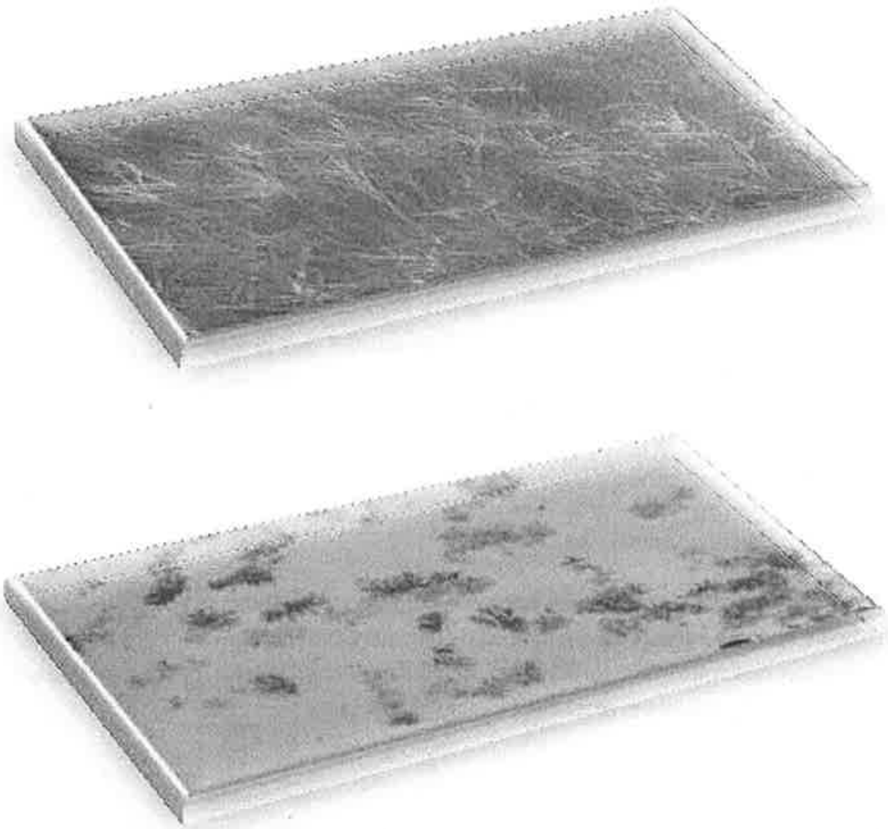
The status of seagrass extent in North West Bay

January 2011



Report for

Kingborough Council, Tasmania

Status report by

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ACKNOWLEDGEMENTS

Jon Doole from the Kingborough Council initiated and funded the project and provided encouragement throughout the course of the project. Stewart Wells successfully mastered the art of through water image capture. Arko Lucieer, UTAS, delivered Oktocopter imagery of Clarkes Beach.

PROJECT OUTPUTS

The project generated several outputs:

1. A set of purpose flown aerial photos along the entire western shore of NWB
2. Meso-scale imagery collected from a remote controlled Oktocopter over Clarkes Beach.
3. A set of mega-quadrats in GIS format along the western shore useful for future comparisons
4. An assessment of seagrass extents over the last 60 years.

CITATION

Mount R. E. and K. Otera 2011 *The status of seagrass extent in North West Bay*. A technical report for the Kingborough Council by the Blue Wren Group, School of Geography and Environmental Studies, University of Tasmania, Hobart, Tasmania.

DISCLAIMER

It must be noted that this project is a rapid assessment of the extent of seagrass in North West Bay based largely on the aerial photographic record, and does not assess the reasons for the observed changes. The estimates of seagrass extent do not include the deeper parts of the seagrass beds as these are generally not visible in standard aerial photography. This means that the estimates of change are based on the shallower seagrass. In North West Bay, the shallowest seagrass beds have had the largest changes in area and change more often compared to the visible deeper beds. The estimates of changes in seagrass extent reported here do not include changes in the deep edge of the seagrass beds. This would be useful information to obtain as it would allow more complete estimates of seagrass extent to be made.

The University of Tasmania uses reasonable means to verify the validity and accuracy of the data contained herein at the date of this report, however to the extent allowed by law, it does not warrant or represent that the data will be correct, current, fit/suitable for a particular purpose or not misleading. Specifically, the data should not be relied upon (that is, professional advice should be sought) if that data is to be used for purposes outside the scope of this project.

Summary

- The Blue Wren Group, School of Geography and Environmental Studies, University of Tasmania have sought to describe the status and trends of the distribution of seagrass communities throughout North West Bay (NWB), South East, Tasmania for Kingborough Council based on existing and new data sets and using rapid "first pass" assessment techniques.

- The objectives of this assessment were to identify the current distribution of seagrass communities, found in NWB, and to detect the long term change in the distribution and biomass of seagrass communities over the last 60 years.

- Informed by previous research efforts, the research methods for this study had four phases; (1) selection of aerial photography for the time series, (2) purpose-driven capture of low-cost aerial photography for the present day, (3) rapid interpretation of the time series of the aerial photography images using "mega-quadrats" (Mount, 2007), and (4) production of charts showing of seagrass habitats density change for each mega-quadrat.

- A total of 5 mega-quadrat locations, including; (1) Dru Point Delta, (2) Barretta Bank, (3) Graham Street Beach (immediately south of the NWB Marina), (4) Snug Beach, and (5) Clarkes Beach were selected in this study. Due to constraints imposed by image quality and availability, two study locations – the Dru Point Delta and Snug Beach – were only analysed for present day seagrass distributions and the analysis does not include the deepest edge of the seagrass beds. The change detection method (image visualisation comparison matrix) makes use of aerial photography and is based on the concept of mega-quadrats. It is effective for detecting change in seagrass distributions.

- The analysis indicates that the extent of seagrass habitat in North West Bay has been in long term decline over the past 60 years with particularly large changes evident in many beds in the mid-1980s, for example, at Clarkes Beach. This long term decline is characterised by frequent short-term irregular fluctuations in seagrass distributions in all the study locations in North West Bay since 1948. Since 2008, the seagrass beds in most mega-quadrats appear to be in a growth phase and the seagrass is recolonising areas it has previously occupied.

- It is beyond the scope of this report to examine the reasons for the decline and they are likely to be multiple with complex feedback interactions. Candidates for further examination include climate variations (e.g. rainfall), nutrient levels (e.g. sewage and fish farming) and direct damage (e.g. mooring and propeller wash).

- Further spatial analysis could usefully be conducted to produce more precise mapping of the seagrass habitats. Higher quality aerial photography, which displays the deep edge of seagrass habitats, would support more thorough analysis. Acquiring such imagery would need to be carefully planned for due to variation in weather and/or water clarity conditions.

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1. Introduction

Seagrass plant communities play an ecologically important role in coastal regions, with the organic matter provision; nutrient trapping and cycling; shore line protection and formation; substrate sediment stabilization; enhanced biodiversity through provision of a structured habitat; and trophic transfers to adjacent habitats. This means they are foundational components of the North West Bay ecosystem and also support many human activities in and around the bay.

The present study was undertaken by the Blue Wren Group, School of Geography and Environmental Studies, University of Tasmania. In response to the request from Kingborough council, the status and trends of seagrass distribution were analysed with reference to the previous assessment of seagrass distribution and biomass in North West Bay (NWB) by Jordan *et al.* (2002).

The objectives of this assessment were to adopt a rapid assessment methodology that would allow efficient identification of the current distribution of seagrass communities, found in NWB, and to detect the trends of change in seagrass distribution over the 60 years since 1948. This report is divide into three sections, with the first describing the method applied for this study and the second presenting the results of change trends in seagrass density. The third section presents the discussion, including the assessment of the change in seagrass distribution and future analysis needs in response to the results.

2. Methods

In summary, the methodology employed in this study has four phases, including; (1) selection of aerial photography for the time series, (2) purpose driven capture of low-cost aerial photography for the present day, (3) rapid interpretation of the time series of the aerial photography images using "mega-quadrats" (Mount, 2007) at selected sites, and (4) production of charts showing changes in seagrass bed extent for each mega-quadrat. It was not possible to conduct detailed aerial photographic assessments such as deep edge assessments due to cost and time constraints and a lack of suitable quality imagery.

2.1. Data acquisition

Aerial photography was chosen as the method of remote sensing for this study. Aerial photographs (3/10/2010) were acquired to provide a snapshot for the present day by Mr. Stewart Wells using a digital SLR Canon D5 from a fixed wing Cessna. Aerial photography between 1948 and 2008 (listed in Appendix 1) stored in Service Tasmania were evaluated and photos of the required quality were then rephotographed with a digital camera (Pentax Optio 60w). This approach meant that the entire range of imagery was able to be subject to visual interpretation at low cost.

2.2. Study Area

North West Bay, located in the South West of Hobart (43°S, 147.25°E) is a sheltered coastal embayment, which is approximately 7 km north to south (Jordan *et al.*, 2002; Mount, 2006). The dominant seagrass species, *Heterozostera tasmanica* is found on the intertidal flats and subtidally to around 10 m depth in a band along the coast. Levels of nitrates in NWB are generally low, with low levels of nutrients in the water between spring and early autumn (Jordan *et al.*, 2002). Current speed in the northern part is slower while the area adjacent to the mouth of bay is faster (Jordan *et al.*, 2002). Local threats to the seagrass communities varies dependent upon its position in NWB, and so five sites were selected for this study distributed from north to south (see map in Figure 1), including;

(1) Dru Point Delta (0.255 Km^2),
(2) Barretta Bank (0.295 Km^2),
(3) Graham Street Beach (0.09 Km^2),
(4) Snug Beach (0.17 Km^2) and
(5) Clarkes Beach (0.099 Km^2).

Large mega-quadrats were set up at each site according to the methods outlined in Mount (2007). This approach is designed to enable rapid efficient image interpretation and has been used by Ball et al. (2008) in Victoria for similar purposes.

In general, the pattern of seagrass distribution in the bay is as follows:

1. Deeper subtidal seagrass beds dominated by *H. tasmanica*
2. Shallow subtidal seagrass beds in either narrow strips or wide patchy beds, again dominated by *H. tasmanica*
3. Intertidal seagrass beds dominated by *Zostera muelleri*

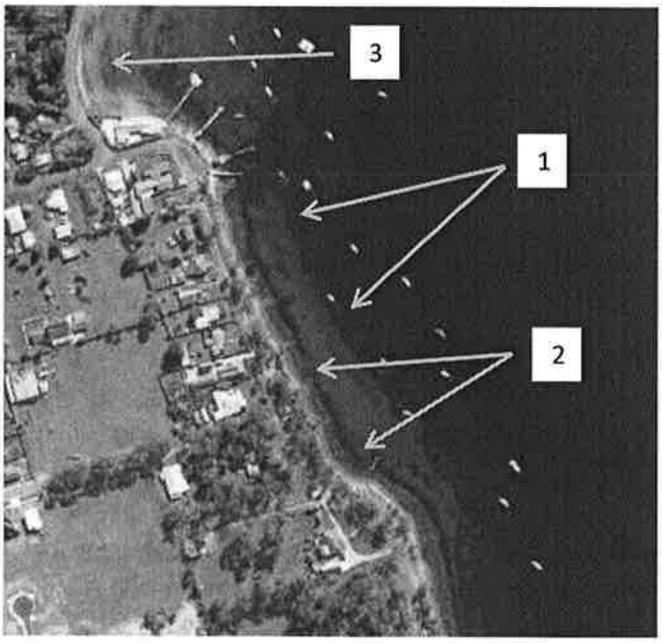

Figure 1. An illustration of the three main distribution patterns of seagrass in North West Bay (see text for explanation of the numbers).

The Dru Point Delta site is located in the north part of the bay where the NWB River enters and is immediately adjacent to the Dru Point boat ramp. Generally, this area has low nitrates levels, yet occasionally, higher levels occur after heavy rain falls in November (Green, 1999; Jordan et al., 2002). Also, a sewage treatment plant is located besides the delta. The changes in salinity and nutrient levels are local seagrass stressors.

Barretta Bank is located in the middle part of NWB. Boat moorings, direct physical damage by propeller wash and hull impacts are considered to be the most likely threats to seagrass habitats in this area. The Graham Street Beach mega-quadrat is located adjacent to the NWB Marina and south of Barretta Bank. This area is also subject to the sewage treatment plant, boat moorings and physical structures.

The Snug Beach mega-quadrat is located south of Graham Street Beach. Potentially, higher turbidity, or lower clarity water, which limits light availability for seagrass growth, may be present due to the plume of the Snug River (Jordan *et al.*, 2002). The Clarkes Beach mega-quadrat is located on the southern shores of NWB and is the closest site to the mouth of the bay. Septic tank leakage identified along this beach may influence seagrass distributions (Jordan *et al.*, 2002) and, possibly, elevated nutrient levels resulting from the scale-fish marine farming in the D'entrecasteaux Channel.

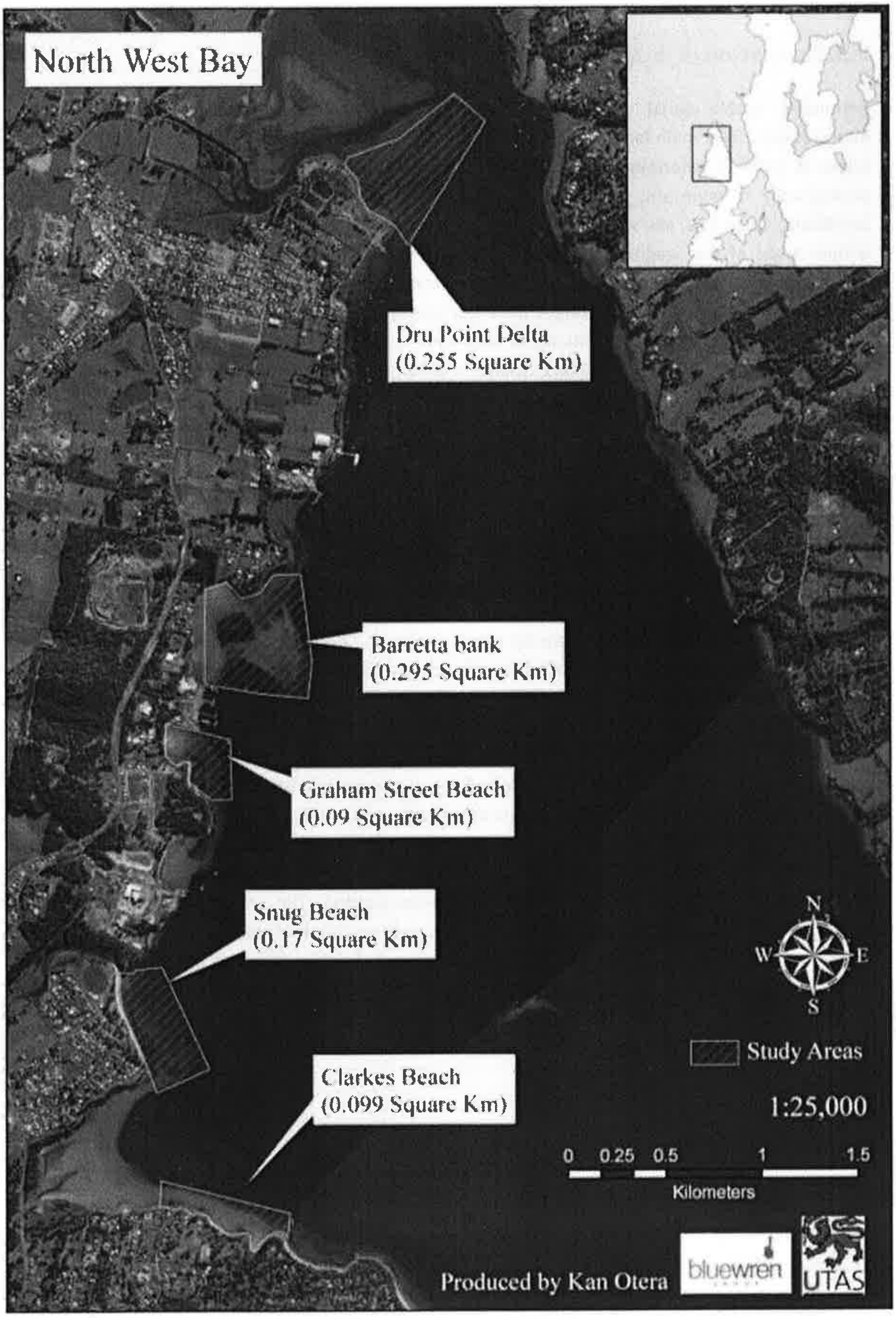

Figure 2. Study sites, or mega-quadrats, in North West Bay. Image source: 2003-2005 QuickBird, Sinclair Knight Merz.

2.3. Estimation of seagrass extent through time

Potentially usable aerial photography between 1948 and 2008 were selected for image interpretation. Two main factors were considered to select optimal aerial photography for the time series. In order to determine the distribution of seagrass communities, the image quality of aerial photography is important. It was important to select images that were acquired with optimal conditions; cloud free, low wind (<10 knots), and low tide to get maximum light penetration so that deeper areas of the seagrass patches are able to be detected. The temporal interval of image acquisition date was also high on the list of considerations as it needs to be at a rate that enables the detection of changes in the target plant community. For example, some intertidal seagrasses potentially change rapidly (i.e. annually or less) while other species are very long-lived and change only slowly (Meehan and West, 2000). Image selection based on a shorter temporal interval was prioritised to support the detection of trends in seagrass distribution and density.

The 5 study locations for this study (Figure 1) are distributed throughout the bay and include; (1) Dru Point Delta, (2) Barretta Bank, (3) Graham Street Beach, (4) Snug Beach, and (5) Clarkes Beach. Due to constraints imposed by image quality and availability, two study locations; the Dru Point Delta and Snug Beach were only analysed for present day seagrass distributions. Visual interpretation of the selected aerial imagery was conducted for Barretta Bank, Graham Street Beach and Clarkes Beach. The image quality also limited interpretation of the deep edge of seagrass habitats.

In order to identify the trends in seagrass extent, seagrass "density" or percent cover within each mega-quadrat (Barretta Bank, Graham Street Beach and Clarkes Beach) was estimated in terms of relative change and absolute change and charted as a time series. The charts of **relative change** depict the proportion of seagrass bed density within each mega-quadrat throughout the time series with the densest and least dense scores of 10 and 1 respectively calibrated against the densest and least dense seagrass beds observed in the full set of images regardless of the absolute coverage within the mega-quadrat. For each mega-quadrat the density values from a minimum of one (i.e. 1 = lowest density) to a maximum of 10 (i.e. 10 = highest density) across all available images are presented in a chart. The percentages shown in the **absolute change** chart indicates the estimated spatial extent of seagrass habitats within each mega-quadrat. The values of both relative and absolute change were assigned by an interpreter based on visual interpretation, not digitised line work. It also must be noted that the value of relative and absolute change is not necessary precise due to the limitations of optical image interpretation including the knowledge of interpreter, the image resolution and the environmental conditions prevailing at the time of image capture such as water clarity and surface glitter (Mount, 2006). The advantage of the method is its speed and low cost while extracting useful information.

3. Results

3.1. Current distribution of seagrass communities

The distribution of seagrass communities on 3rd October 2010 in the five study locations in NWB is presented in Figures Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7.

The image of Dru Point Delta displays the sparse seagrass distribution in the south of channel, particularly along the bank edge. Also patchy distribution of seagrass communities appears in the delta. Barretta Bank has approximately 45% coverage of seagrass in the mega-quadrat. The coverage of seagrass communities in Graham Street Beach appears to be approximately 45% of the mega-quadrat in study location. Snug Beach was covered by the approximately 50% of seagrass habitats, particularly along the southern edge of bank.

3.2. Estimation of seagrass extent through time

Figures Figure 8, Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13 present the results of the relative and absolute change of seagrass extent in the mega-quadrats of Barretta Bank, Graham Street Beach and Clarkes Beach. In summary, irregular and frequent changes in seagrass extent, with gains and losses have occurred in the mega-quadrats while the total extent of seagrass community through the time period over 60 years has been in decline with a particularly large change evident in many beds in the mid-1980s, particularly at Clarkes Beach. Since 2008, the seagrass beds in all mega-quadrats appear to be in a growth phase and the seagrass is recolonising areas it has previously occupied.

Barretta Bank scored a density level of 10 in February and March in 1977 (Figure 14), which is 85% coverage of seagrass extent in the mega-quadrat. On the other hand, a density score of 1 was allocated for January, February and March in 1988 (Figure 15) and 2002, 2004, 2007 and 2008 (Figure 16). However, the latest aerial photography, acquired in October 2010 shows a recovery in seagrass extent, with a score of 4.5 (Figure 4). Relatively stable areas of seagrass habitats (green polygon) were found along the edge of bank (Figure 4). Frequently changing areas (orange polygon) were found in the central shallow area of the bank. The areas that fluctuated between scores of 10 and 1 through time were mainly in the shallower depths. The seagrass beds that have been growing back since 2008 are mostly within these frequently changing zones.

The Graham Street Beach recorded 10 for seagrass density in February 1967 (Figure 17) and 1985 (Figure 18), and October 1981, which is 80% coverage. A score of 1, with 25% coverage was recorded in February 2008 whereas seagrass density has grown back to a score of 5, with the coverage of 45% in October 2010. Most of the Graham Street Beach mega-quadrat is in shallow areas that have been subject to frequent changes in seagrass area (orange polygon, Figure 5). The areas showing seagrass losses are generally found within the depth zone that experiences frequent changes in this mega-quadrat, though losses are apparent to the south east of the marina where boat mooring scour marks are apparent in earlier photos appear to have significant losses of seagrass.. Stable areas (green polygon) have been found adjacent to the frequent change area in both shallow and deeper areas in south part of the quadrat.

Clarkes Beach has recorded step changes of seagrass area loss since 1948 (Figure 19), with densities of 50% coverage or higher recorded up until 1985, then dropping off to 10 and 20%. The density score has seen almost no change between 1985 and 2008 with the lowest density recorded in 2001 (Figure 20). The most recent imagery from December 2010 displays prolific and rapid growth of seagrass patches in the beach (Figure 22 and Figure 23). The narrow bands of stable areas (green polygon) were identified along the edge of reef, which is 5-10m from shoreline (Figure 7). The relatively thick band of seagrass beds (red polygon) were all gone between 1948 and 1985 (Figure 19), which used to stretch from west to east and located between the nearshore stable area and offshore stable area (Figure 7).

Figure 3. Dru Point Delta mega-quadrat with indicative seagrass boundaries shown to illustrate the general location of the seagrass.

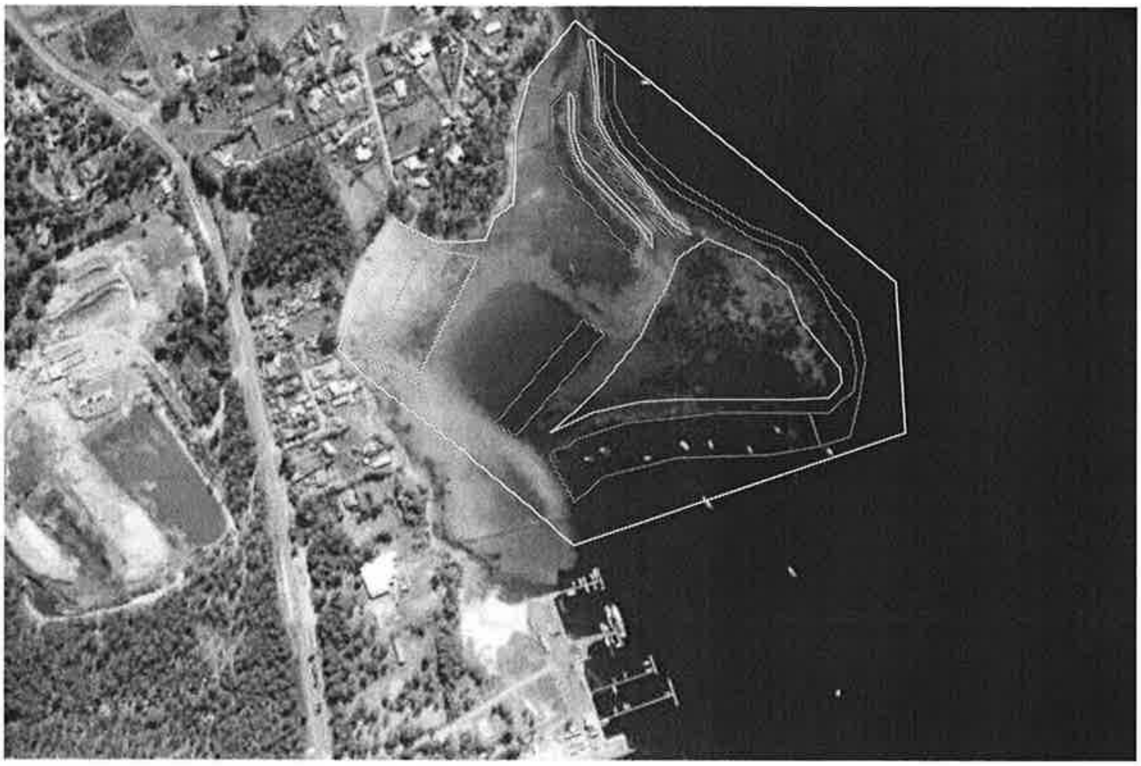

Figure 4. Barretta Bank mega-quadrat with indicative seagrass boundaries shown to illustrate the general location of the seagrass.

Figure 5. Graham Street Beach mega-quadrat with indicative seagrass boundaries shown to illustrate the general location of the seagrass.

Figure 6. Snug Beach mega-quadrat with indicative seagrass boundaries shown to illustrate the general location of the seagrass.

Figure 7. Clarkes Beach mega-quadrat with indicative seagrass boundaries shown to illustrate the general location of the seagrass.

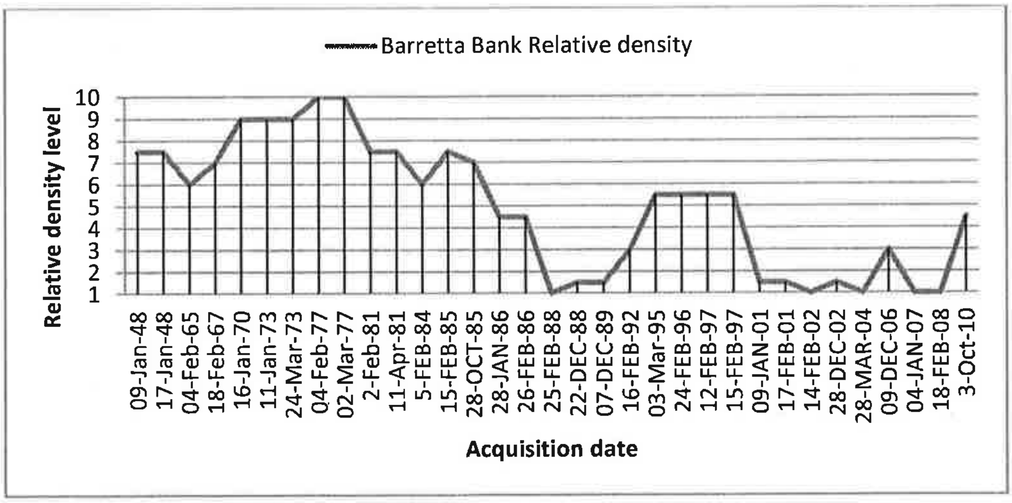

Figure 8. Relative density chart of Barretta Bank

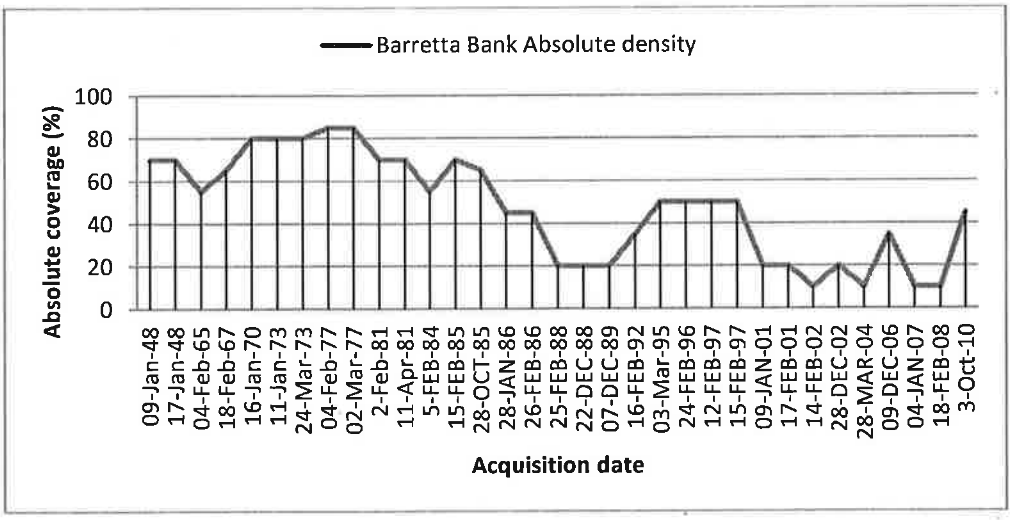

Figure 9. Absolute density chart of Barretta Bank

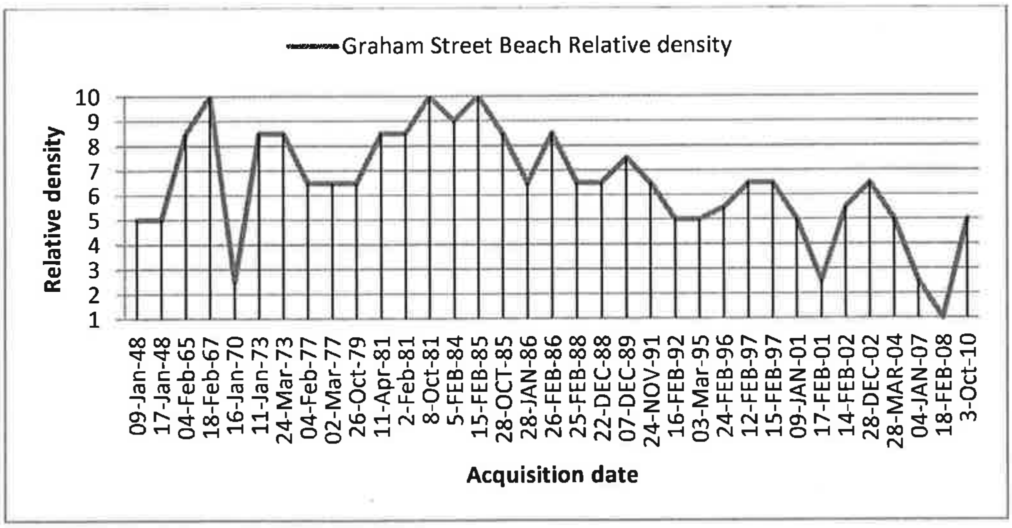

Figure 10. Relative density chart of Graham Street Beach

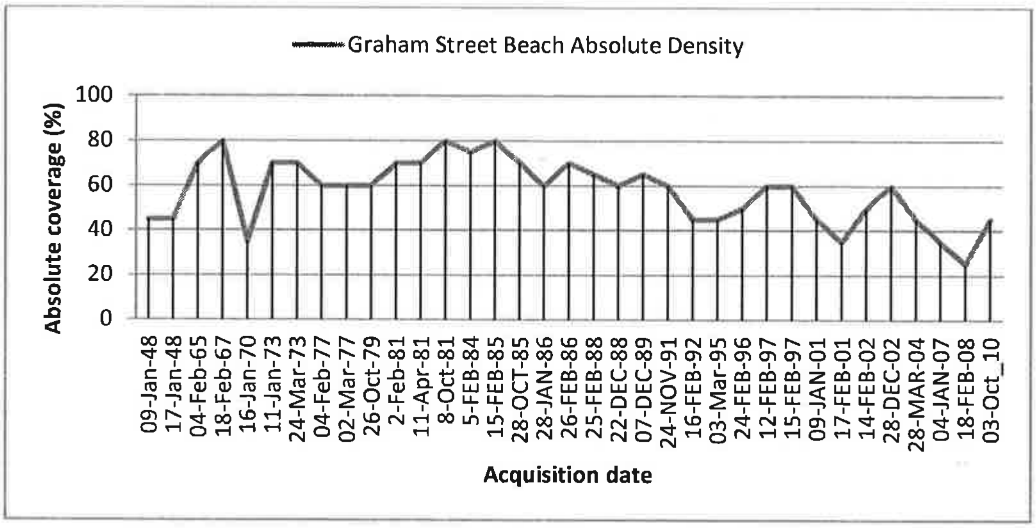

Figure 11. Absolute density chart of Graham Street Beach

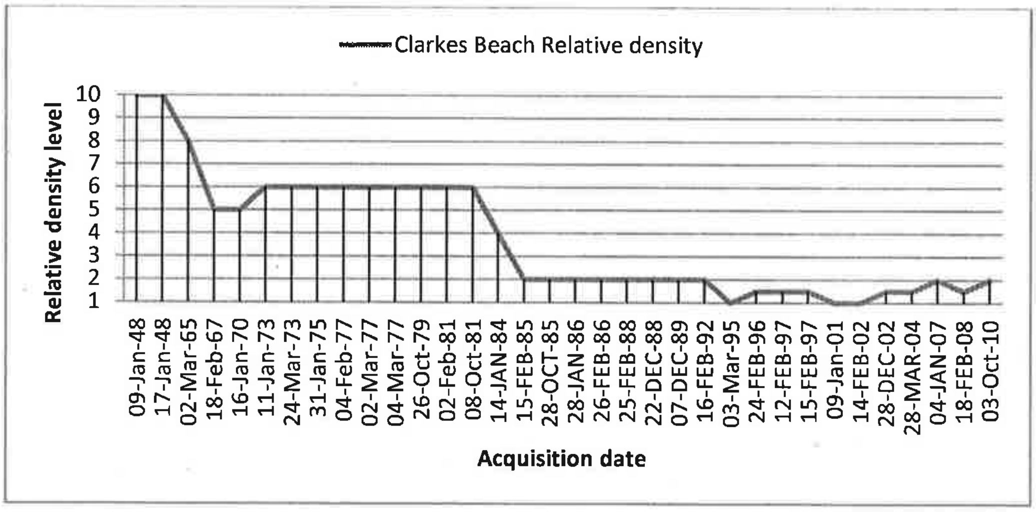

Figure 12. Relative density chart of Clarkes Beach

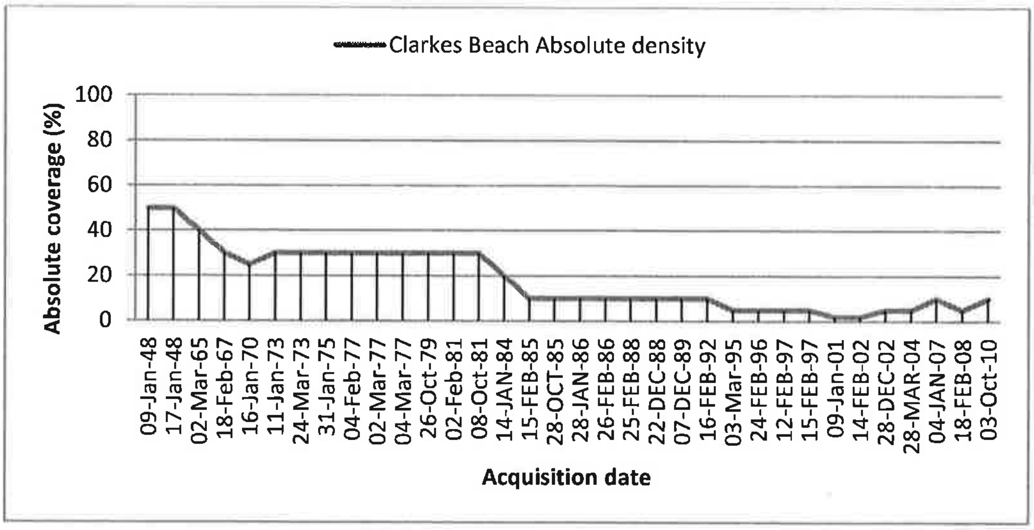

Figure 13. Absolute density chart of Clarkes Beach

4. Discussion

It must be noted that this project is a rapid assessment of the extent of seagrass in North West Bay based largely on the aerial photographic record, and does not assess the reasons for the observed changes.

The analysis indicates that the seagrass beds of North West Bay are in long-term decline and exhibit irregular, frequent and substantial gains and losses in the study locations over the period between 1948 and 2010. One conclusion to draw from this observation is that the seagrass species in the bay are, relative to some other seagrass species, capable of actively and repeatedly colonising and recolonising the sea floor.

Drawing on the **time series estimates**, all study locations had their highest densities between the 1970's and the mid-1980's. Since then, the total extent of seagrass in NWB began a downward trend, with irregular gains and losses until 2008. Since 2008, the general trend of seagrass extent in each mega-quadrat appears to be generally up, especially in the areas which have shown frequent changes in the past. NWB is mainly dominated by *Heterozostera tasmanica*, or eelgrass, (Jordan *et al.*, 2002) and, although the causes of the long term trends found in this study are yet to be explained, the observed frequent changes in nearshore shallow flats is a recognised characteristic of *H. tasmanica*. A particularly strong finding was the long term stepped decreases in the seagrass communities at Clarkes Beach though until 2001, when it was almost completely absent, with only 2% coverage in the mega-quadrat (Figure 19). The characteristics of this beach is different from others, as it is facing toward north and also located closer to the mouth of bay.

Within the three mega-quadrats of Barretta Bank, Graham Street Beach and Clarkes Beach, there are both stable areas and more frequently changing areas. The stable areas appear to be along the bank edge parallel to the coastline in the form of narrow linear patches. The frequently changing areas run parallel in between the stable patches. Since both stable and frequently changed areas are located within around 20-30 m of each other, local factors related to specific depths appear to be important, perhaps including bioturbation by benthic macro-invertebrates.

For the **present day distribution** of seagrass communities, the highest density of seagrass was found on Barretta Bank. Even though the seagrasses at Barretta Bank, Graham Street Beach and Clarkes Beach have begun expanding the area they cover since 2008, the abundance of seagrass communities is still lower than in the 1970's and early 1980's. Dru Point Delta currently has a narrow band of discontinuous seagrass patches along the delta's edge that is similar to that in the February 2001 (Figure 24). A second band of seagrass running parallel to the coast line seems denser than in the 2001 image. The distribution and density of seagrass patches in Snug Beach in 2010 was similar to 2001 (Figure 25). Sparse seagrass patches in the bank (green polygon) (Figure 6) is particularly well matches with those in 2001. The total extent of seagrass in this mega-quadrat between 2001 and 2010 also appears similar.

Comment on the study method

The present study used optical image interpretation of aerial photography time series. There are some limitations in the method and the data sources that should be understood. Firstly, simply observing aerial images and estimating which dark patches under water are seagrass and differentiating them form algae (seaweeds) is challenging process. In this case, a skilled habitat mapper conducted most of the work assisted by a highly experienced habitat mapper who knows the study area's habitats in detail. Some field observations were taken to support the process using GPS and underwater camera photos.

Secondly, the estimates of seagrass extent do not include the deeper parts of the seagrass beds as these are generally not visible in standard aerial photography. This means that the estimates of change are based on the shallower seagrass. In North West Bay, the shallowest seagrass beds have had the largest changes in area and change more often compared to the visible deeper beds. The estimates of changes in seagrass extent reported here do not include changes in the deep edge of the seagrass beds. This would be useful information to obtain as it would allow more complete estimates of seagrass extent to be made.

In spite of its limitations, the *image visualisation comparison matrix* change detection method, involving the use of aerial photography based on the analysis of "mega-quadrats" (Mount, 2007), is considered to be a cost effective way of estimating large scale changes in seagrass distribution.

The method employed for this study should be considered as producing qualitative results rather than quantitative data. In order to obtain more precise results with quantitative values, further analysis could be conducted by mapping the seagrass habitats to generate more precise distributions of seagrass communities through time. Another challenge for seagrass habitats change detection is the acquisition of high quality aerial photography, which displays the deep edge of seagrass habitats.

5. Next steps...

Seagrasses are bio-indicators, which are subject to rapid environmental changes arising from not only natural causes but also human-induced pressures, such as coastal development, toxicant releases, sewage discharges and sediment run-off. Information on the extent and status of seagrass communities are needed to support the sustainability of not only native natural environment but also the quality of life of the local people. Thus, it is essential to conduct appropriate survey of mapping or monitoring seagrass communities in regular period.

1. Given the time scales that the seagrass extent varies upon, it is recommended that annual low-cost aerial surveys are conducted and the mega-quadrat data updated. It would be useful to do a more complete review about every 5 years.

2. Seagrasses assist in shoreline protection by absorbing wave energy and trapping sediments. They are likely to respond to sea level rise by adjusting the height of the sea floor upwards. It would be useful to examine the feasibility of rehabilitating areas known to have supported seagrass in the past. Methods are under active development by the South Australian Coastal Protection Board (Doug Fotheringham, pers. comm.) and there is a wide research literature available (e.g. Kenworthy and Fonseca, 1992; Fonseca et al., 1998; Meehan and West, 2002).

3. It would be useful to identify more clearly some of the causes of seagrass decline in North West Bay to assist management of the threats. For example, an analysis of the climatic records, population change and other major influences on the bay over the seagrass time series time period may assist with that process.

4. The knowledge currently available from the literature and as applied specifically to North West Bay (e.g. Jordan et al., 2002) indicates that the main threats to seagrass to focus on are excess sediments, excess nutrient, toxicants (e.g. herbicides), direct damage and shading effects. Efforts to reduces these threats need to focus on:

    a. Management of excess sediment loads in the water column

    b. Management of excess nutrient loads in the water column

    c. Management of toxicant releases in to the bay

    d. Management of direct impacts on the bottom by, for example, boats, especially propeller wash impacts and mooring scours.

        i. Prop wash can be reduced with reduced speeds and better marking or shallow seagrass banks.

        ii. Mooring scours can be completely eradicated with the use of seagrass friendly moorings (e.g. see Derbyshire, 2006).

    e. Management of shading effects from structures over the water by, for example, ensuring grating decks on jetties (e.g. Derbyshire, 2006)

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Appendix 1: Aerial photography listing

FLOWN	SCALE	PHOTO Code	Covered location (PP= Principal Point)	HEIGHT	Source
17-Jan-48	1:15840	IMGP3142	Snug & ConH offShorePP		
17-Jan-48	1:15840	IMGP3144	Marina offShorePP	12 000'	Service TAS
17-Jan-48	1:15840	IMGP3146	Marina & Margate OnShorePP	12 000'	Service TAS
17-Jan-48	1:15840	IMGP3148	Margate onShorePP	12 000'	Service TAS
09-Jan-48	1:15840	IMGP3150	Marina & Margate OnShorePP	12 000'	Service TAS
09-Jan-48	1:15840	IMGP3153	Marina & Margate OnShorePP	12 000'	Service TAS
09-Jan-48	1:15840	IMGP3157	Marina & Margate OnShorePP	12 000'	Service TAS
09-Jan-48	1:15840	IMGP3161	Marina & Margate OffShorePP	12 000'	Service TAS
09-Jan-48	1:15840	IMGP3164	Snug & ConH offShorePP	12 000'	Service TAS
02-Mar-65	1:31680	IMGP3166	Margate offShorePP	13 000'	Service TAS
17-Feb-65	1:15840	IMGP3168	Margate offShorePP	12 200'	Service TAS
04-Feb-65	1:15840	IMGP3170	Marina offShorePP	12 200'	Service TAS
02-Mar-65	1:15840	IMGP3176	Snug & ConH offShorePP	12 200'	Service TAS
18-Feb-67	1:15840	IMGP3178	Margate offShorePP	12000'	Service TAS
18-Feb-67	1:15840	IMGP3180	Marina & Margate OffShorePP	12000'	Service TAS
18-Feb-67	1:15840	IMGP3182	Marina & Margate OffShorePP	12000'	Service TAS
18-Feb-67	1:15840	IMGP3187	Snug & ConH offShorePP	12000'	Service TAS
17-Dec-69	1:6000	IMGP3189	Margate offShorePP	2400'	Service TAS
17-Dec-69	1:6000	IMGP3190	Margate offShorePP	2400'	Service TAS
16-Jan-70	1:34770	IMGP3064	Margate onShorePP	13 000'	Service TAS
16-Jan-70	1:34770	IMGP3066	Margate offShorePP	13 000'	Service TAS
16-Jan-70	1:34770	IMGP3068	Marina & Margate OffShorePP	13 000'	Service TAS
16-Jan-70	1:34770	IMGP3072	Marina & Margate OnShorePP	13 000'	Service TAS
16-Jan-70	1:34770	IMGP3076	Snug & ConH onShorePP	13 000'	Service TAS
24-Mar-73	1:12500	IMGP3078	Snug & ConH offShorePP	8700'	Service TAS
24-Mar-73	1:12500	IMGP3080	Marina offShorePP	8700'	Service TAS
24-Mar-73	1:12500	IMGP3083	Margate offShorePP	8700'	Service TAS

24-Mar-73	1:12500	IMGP3085	Margate offShorePP		Service TAS
11-Jan-73	1:8000	IMGP3086	Marina onShorePP	3200'	Service TAS
11-Jan-73	1:8000	IMGP3088	Snug & ConH offShorePP	3200'	Service TAS
11-Jan-73	1:8000	IMGP3090	Snug & ConH onShorePP	3200'	Service TAS
31-Jan-75	1:20000	IMGP3092	Snug & ConH onShorePP	11000'	Service TAS
04-Mar-77	1:30000	IMGP3094	Snug & ConH onShorePP		Service TAS
02-Mar-77	1:30000	IMGP3096	Marina & ConH offShorePP	15700'	Service TAS
02-Mar-77	1:30000	IMGP3101	Marina & ConH offShorePP	15700'	Service TAS
02-Mar-77	1:30000	IMGP3104	Marina & Margate offShorePP	15700'	Service TAS
04-Feb-77	1:30000	IMGP3106	Marina & Margate offShorePP	15700'	Service TAS
04-Feb-77	1:30000	IMGP3110	Marina & Margate offShorePP	15700'	Service TAS
26-Oct-79	1:6000	IMGP3113	ConingH onShorePP	6 000'	Service TAS
26-Oct-79	1:6000	IMGP3115	Marina onShorePP	6 000'	Service TAS
11-Apr-81	1:27000	IMGP3117	Marina & Margate OnShorePP	13800'	Service TAS
11-Apr-81	1:27000	IMGP3121	Margate onShorePP	13800'	Service TAS
2-Feb-81	1:15000	IMGP3123	Margate offShorePP	16 000'	Service TAS
2-Feb-81	1:15000	IMGP3128	Snug & ConH offShorePP	17 500'	Service TAS
2-Feb-81	1:15000	IMGP3125	Marina & Margate OffShorePP	17 500'	Service TAS
8-Oct-81	1:6000	IMGP3131	ConingH onShorePP	6 000'	Service TAS
8-Oct-81	1:6000	IMGP3132	ConingH onShorePP	6 000'	Service TAS
8-Oct-81	1:6000	IMGP3133	ConingH onShorePP	6 000'	Service TAS
8-Oct-81	1:6000	IMGP3137	ConingH onShorePP	6 000'	Service TAS
8-Oct-81	1:6000	IMGP3138	Marina onShorePP	6 000'	Service TAS
8-Oct-81	1:6000	IMGP3140	Marina onShorePP	6 000'	Service TAS
11-JAN-84	1:20000	IMGP2979	Margate offShorePP	20000	Service TAS
14-JAN-84	1:15000	IMGP2981	ConingH onShorePP	15000	Service TAS
5-FEB-84	1:20000	IMGP2983	Marina & Margate OnShorePP	21000	Service TAS
5-FEB-84	1:20000	IMGP2986	Marina & Margate OffShorePP	21000	Service TAS
5-FEB-84	1:20000	IMGP2990	Margate offShorePP	21000	Service TAS
15-FEB-85	1:10000	IMGP2992	ConingH offShorePP	10050	Service TAS

15-FEB-85	1:10000	IMGP2994	Snug & ConH onShorePP	10050	Service TAS
15-FEB-85	1:10000	IMGP2996	Marina onShorePP	10050	Service TAS
15-FEB-85	1:10000	IMGP3000	Margate onShorePP	10050	Service TAS
28-OCT-85	1:15000	IMGP3002	Snug & ConH onShorePP	16500	Service TAS
28-OCT-85	1:15000	IMGP3004	Marina & ConH offShorePP	16500	Service TAS
28-OCT-85	1:15000	IMGP3008	Margate offShorePP	16500	Service TAS
28-OCT-85	1:15000	IMGP3010	Margate & Nmarina OnShorePP	16500	Service TAS
28-JAN-86	1:28000	IMGP3013	Marina & ConH offShorePP	14000	Service TAS
28-JAN-86	1:28000	IMGP3017	Marina & Margate OnShorePP	14000	Service TAS
26-FEB-86	1:12500	IMGP3021	Margate offShorePP	12700	Service TAS
26-FEB-86	1:12500	IMGP3023	Margate offShorePP	12700	Service TAS
26-FEB-86	1:12500	IMGP3025	Marina onShorePP	12700	Service TAS
26-FEB-86	1:12500	IMGP3028	Snug & ConH onShorePP	12700	Service TAS
04-FEB-88	1:12500	IMGP3030	Margate offShorePP	6450	Service TAS
25-FEB-88	1:12500	IMGP3032	Marina onShorePP	6450	Service TAS
25-FEB-88	1:12500	IMGP3037	Snug & ConH onShorePP	6450	Service TAS
22-DEC-88	1:12500	IMGP3040	Snug & ConH onShorePP	6500	Service TAS
22-DEC-88	1:12500	IMGP3042	Marina onShorePP	6500	Service TAS
22-DEC-88	1:12500	IMGP3045	Margate offShorePP	6500	Service TAS
22-DEC-88	1:12500	IMGP3047	Margate offShorePP	6500	Service TAS
07-DEC-89	1:12500	IMGP3050	Marina onShorePP	12800	Service TAS
07-DEC-89	1:12500	IMGP3053	Snug & ConH onShorePP	12800	Service TAS
07-DEC-89	1:12500	IMGP3055	Marina & Margate OffShorePP	12800	Service TAS
07-DEC-89	1:12500	IMGP3059	Margate offShorePP	12800	Service TAS
07-DEC-89	1:12500	IMGP3061	Margate offShorePP	12800	Service TAS
24-NOV-91	1:3000	IMGP3063	Marina onShorePP	3000	Service TAS
16-FEB-92	1:12500	IMGP2907	Snug & ConH onShorePP	12800	Service TAS
16-FEB-92	1:12500	IMGP2908	Marina onShorePP	12800	Service TAS
16-2-92	1:12500	IMGP2910	Margate offShorePP	12800	Service TAS
16-2-92	1:12500	IMGP2912	Marina offShorePP	12800	Service TAS

3-3-95	1:12500	IMGP2914	Snug & ConH onShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2915	Marina onShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2916	Marina onShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2919	Margate offShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2921	Margate offShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2922	Marina offShorePP	12800	Service TAS
3-3-95	1:12500	IMGP2925	Snug & ConH offShorePP	12800	Service TAS
24-FEB-96	1:20000	IMGP2926	Snug & ConH offShorePP	22000	Service TAS
24-FEB-96	1:20000	IMGP2927	Marina & Margate OffShorePP	22000	Service TAS
24-FEB-96	1:20000	IMGP2930	Margate offShorePP	22000	Service TAS
12-FEB-97	1:24000	IMGP2932	Marina & ConH offShorePP	12500	Service TAS
12-FEB-97	1:24000	IMGP2934	Marina & Margate OffShorePP	12500	Service TAS
15-FEB-97	1:12500	IMGP2937	ConH onShorePP	12800	Service TAS
15-FEB-97	1:12500	IMGP2938	Marina offShorePP	12800	Service TAS
15-FEB-97	1:12500	IMGP2940	Margate offShorePP	12800	Service TAS
15-FEB-97	1:12500	IMGP2942	Margate offShorePP	12800	Service TAS
15-FEB-97	1:12500	IMGP2943	Marina onShorePP	12800	Service TAS
15-FEB-97	1:12500	IMGP2945	Snug & ConH onShorePP	12800	Service TAS
09-JAN-01	1:24000	IMGP2946	Marina & ConH offShorePP	12500	Service TAS
09-JAN-01	1:24000	IMGP2949	Marina & Margate OnShorePP	12500	Service TAS
17-FEB-01	1:24000	IMGP2950	Marina & Margate OnShorePP	14000	Service TAS
19-JAN-02	1:20000	IMGP2953	Margate offShorePP	22500	Service TAS
14-FEB-02	1:20000	IMGP2954	Snug & ConH onShorePP	22500	Service TAS
14-FEB-02	1:20000	IMGP2955	Marina Margate & ConH offShorePP	22500	Service TAS
23-NOV-02	1:10000	IMGP2958	Margate offShorePP	5800	Service TAS
28-DEC-02	1:12500	IMGP2959	Snug & ConH onShorePP	6350	Service TAS
28-DEC-02	1:12500	IMGP2960	Marina onShorePP	6350	Service TAS
28-DEC-02	1:12500	IMGP2962	Margate onShorePP	6350	Service TAS
28-MAR-04	1:24000	IMGP2963	Marina Margate & ConH onShorePP	12500	Service TAS
28-MAR-04	1:24000	IMGP2964	Marina & Margate OnShorePP	12500	Service TAS

09-DEC-06	1:10000	IMGP2968	Margate onShorePP	5400	Service TAS
09-DEC-06	1:10000	IMGP2969	Marina & Margate OnShorePP	5400	Service TAS
04-JAN-07	1:12500	IMGP2970	Margate onShorePP	6350	Service TAS
04-JAN-07	1:12500	IMGP2971	Marina & Margate OnShorePP	6350	Service TAS
04-JAN-07	1:12500	IMGP2973	Marina onShorePP	6350	Service TAS
04-JAN-07	1:12500	IMGP2974	Snug & ConH onShorePP	6350	Service TAS
18-FEB-08	1:24000	IMGP2975	Marina & Margate OnShorePP	12500	Service TAS
18-FEB-08	1:24000	IMGP2978	Marina & ConH onShorePP	12500	Service TAS
3-Oct-10		sw_Margate-snug-Run 3 image 1		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 2		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 3		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 4		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 5		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 6		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 7		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 8		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 9		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 3 image 10		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 1 image 2		5000	Stewart Wells
3-Oct-10		sw_Margate-snug-Run 1 image 3		5000	Stewart Wells

Appendix 2: Aerial photography images: selected time series

Figure 14. Barretta bank in 1977 with a relative density score of 10

Figure 15. Barretta Bank in 1988 with a relative density score of 1

Figure 16. Barretta Bank and Graham Street Beach in 2008 with a relative density score of 1

Figure 17. Graham Street Beach in 1967 with a relative density score of 10

Figure 18. Graham Street Beach in 1985 with a relative density score of 10

Figure 19. Clarkes Beach in 1948 with a relative density score of 10

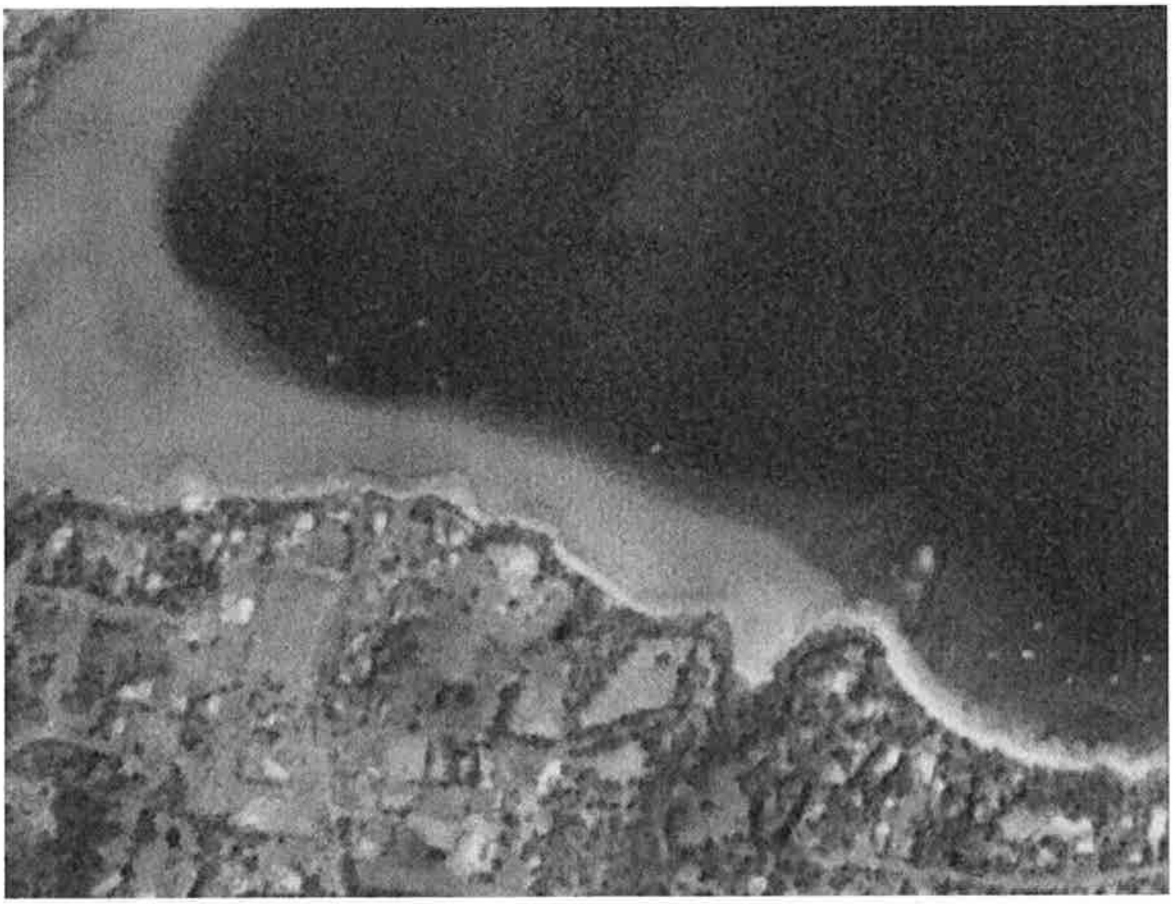

Figure 20. Clarkes Beach in 2001 with a relative density score of 1

Figure 21. Clarkes Beach in 1985 with a relative density score of 2

Figure 22 Clarkes Beach: Oktocopter remote controlled images captured on 31/12/2010 by Arko Lucieer, UTAS.

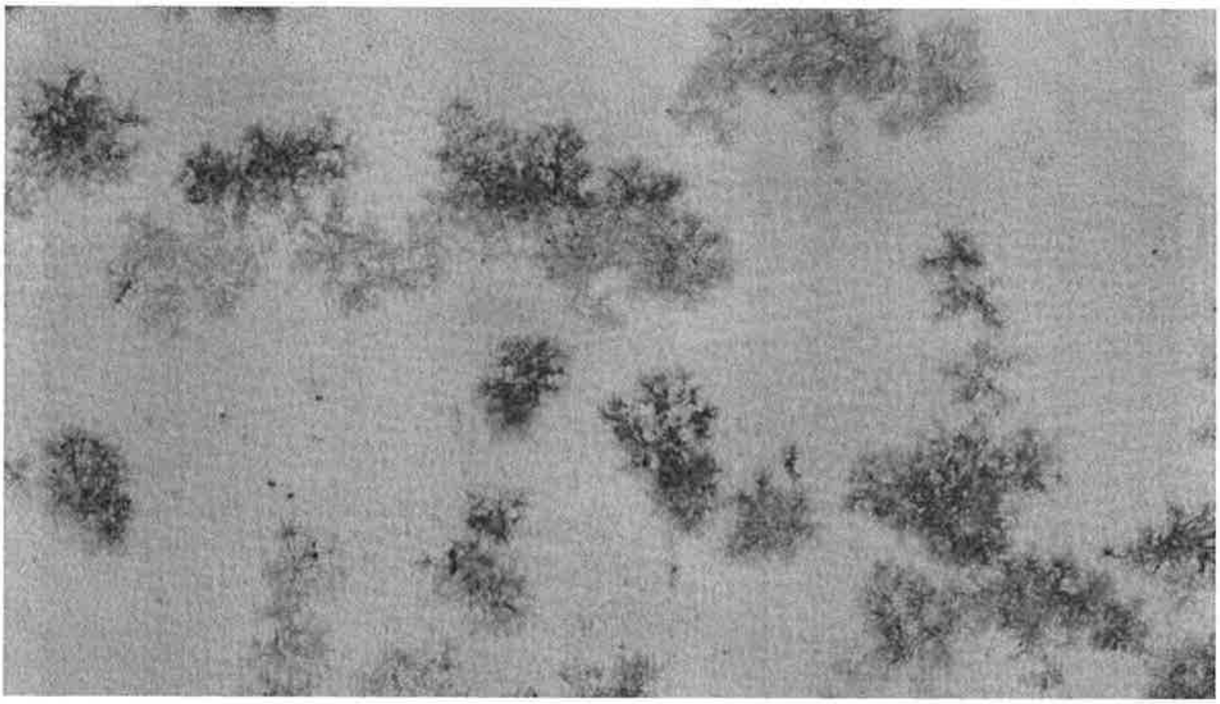

Figure 23 Close-up of Figure 21 showing sparse seagrass but with consistent patterns of expanding rhizomes of *Heterozostera tasmanica*

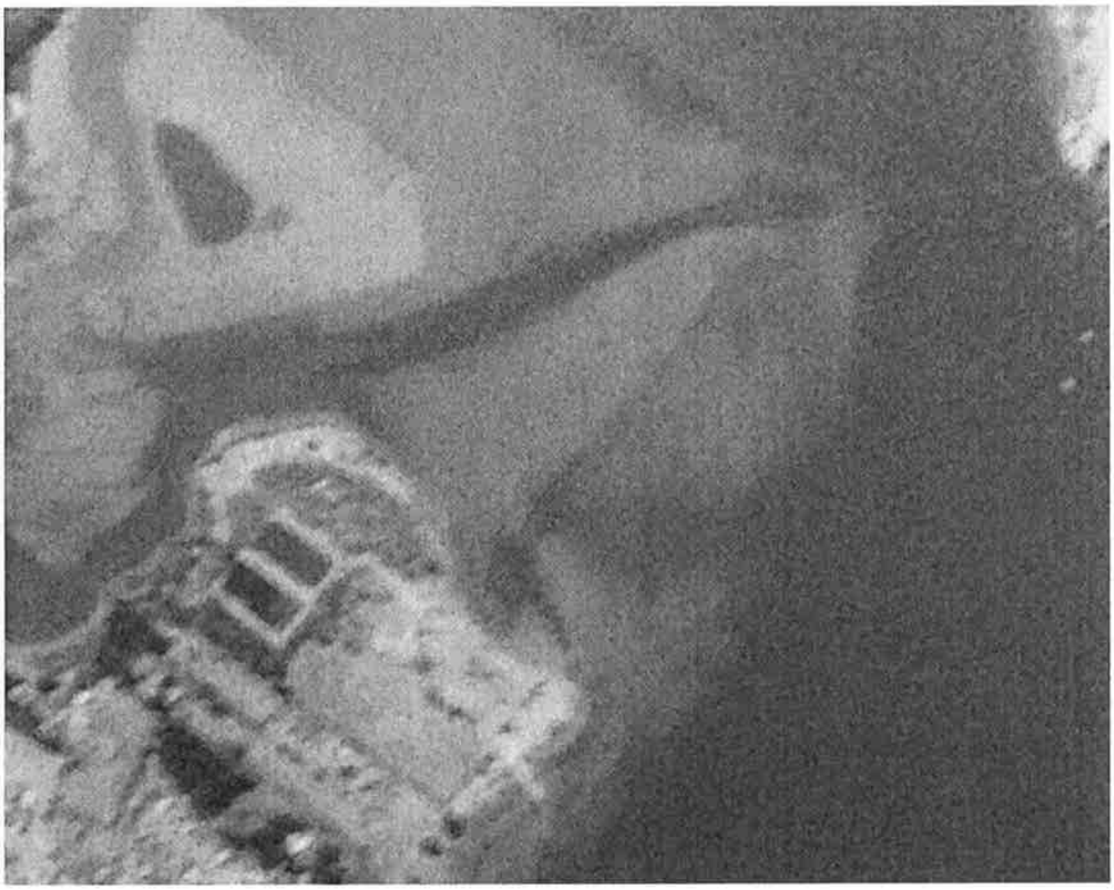

Figure 24. 2001 Dru Point Delta

Figure 25. 2001 Snug Beach